# WATER EXTRACTION FROM COAL-FIRED POWER PLANT FLUE GAS

Quarterly Progress Report

*For the period of October 1 – December 31, 2003*

*Prepared for:*

AAD Document Control

U.S. Department of Energy
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Cooperative Agreement No. DE-FC26-03NT41907
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May 2004

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## ABSTRACT

This quarterly report lists activities performed for the subject project. The project is divided into ten tasks. Task 1 calls for the selection of desiccants to test in Task 2 in a small-scale combustion test furnace at the Energy & Environmental Research Center. Task 1 has been completed. Task 2 bench-scale testing of the desiccant performance under actual combustion conditions was initiated. To aid in the process condition selection for the Task 2 combustion tests, modeling work used to simulate different conditions was performed. This will allow the selection of the most beneficial test conditions for Task 2.

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### EXECUTIVE SUMMARY

The goals of the project are to develop technology for recovering water from combustion flue gases to reduce the net water requirements of power plants burning fossil fuels and to perform an engineering evaluation to determine how such technology can be integrated into various power-generating systems, including steam turbine and combined-cycle plants. In the past, power plants burning fossil fuels were designed to generate electricity at least cost under circumstances of abundant coal and natural gas resources and adequate supplies of water for plant cooling. Future plants will need to be designed and operated to conserve both fuel and water. Water is becoming scarce and expensive in many parts of the United States including California, where there is already a strong economic incentive to reduce the net cooling water requirements of power plant subsystems cooling steam turbine condensers and scrubbing stack gases.

Future escalation in the price for natural gas and possible restrictions on carbon emissions from fossil fuels will likewise provide a strong incentive for increasing generating efficiencies. Coal utilization would be most severely impacted by climate change policy initiatives since a coal-fired steam plant emits nearly three times more $CO_2$ than a natural gas-fired combined-cycle plant with similar generating capacity. Issues of heat and mass transfer concerned with water recovery, plant efficiency, and emissions are all related, so technical options for recovering water will open up new opportunities for improving performance relating to the other two factors.

The project is divided into ten tasks as follows:

- Task 1. Desiccant Selection
- Task 2. Desiccant Laboratory Test Evaluation
- Task 3. Test Plan Development
- Task 4. Test Facility and Equipment Design
- Task 5. Equipment and Materials Procurement
- Task 6. Test Equipment Installation
- Task 7. Testing
- Task 8. Test Data Evaluation
- Task 9. Commercial Power Plant Evaluation
- Task 10. Program Management

A kickoff meeting was held at the University of North Dakota (UND) Energy & Environmental Research Center (EERC) on November 6, 2003. Attendees were Ms. Barbara Carney of the Department of Energy (DOE) National Energy Technology Laboratory (NETL) and Dr. Bruce Folkedahl, Dr. Michael Jones, Mr. Greg Weber, and Dr. Everett Sondreal, all of UND EERC. Attendees from Siemens Westinghouse Power Corporation (SWPC) were Mr. Lloyd Dean, Mr. Phil Deen, Mr. Dick Newby, and Mr. Eric Weinstein.

Communication protocols for the project were developed, as were a formalized statement of project responsibilities for each of the tasks listed above and who will be the lead investigator.

In this quarter, Task 1 was completed and Task 2 initiated. Three desiccants were selected for further analysis in Task 2. Several efforts to define the process parameters for testing in Task 2 were performed, including modeling work of potential systems. These efforts will be used to develop a test plan and perform the combustion testing in Task 2 in the next quarter.

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## EXPERIMENTAL

Task 1 was completed in this quarter, and Task 2 was initiated. Task 2 consists of developing a test plan for analyzing the desiccants using the Energy & Environmental Research Center (EERC) conversion and environmental process simulator (CEPS). The CEPS is illustrated in Figure 1. The CEPS is designed to nominally top-fire 4.4 lb/hr (2 kg/hr) of pulverized coal, with a heat input of 40000 Btu/hr. Other solid or liquid fuels can be utilized with slight system modifications. It is designed to maintain the flue gas (approximately 8 scfm) generated by the combustion of the fuel at a maximum of 1500°C (2732°F) for the first 4 m (12 ft) of the system, which is referred to as the radiant zone. The first 3 m (9 ft) of the heated radiant zone has an inside diameter (i.d.) of 15.2 cm (6 in.), with the last heated zone reducing down to 7.62 cm (3 in.). The radiant zone exit is through a horizontal, 3.8-cm (1.5-in.)-i.d. ceramic tube. A portion of the particulate is removed before the convective pass section of the CEPS. After the convective section, flue gas flows through an optional ash-fouling test section, a baghouse for final removal of particulate, an air eductor, and up to a stack through the roof. CEPS is a sealed system maintained under a slight vacuum with an eductor. Electrically heated sections have ceramic tubes exposed to four high-temperature molybdenum silicide heating elements surrounded by high-temperature, fibrous insulating board. Access to the inside of the combustor is available at a number of locations in the radiant zone for sampling, observation, and optical analyses. Access ports penetrate through a combination of cast, abrasion-resistant

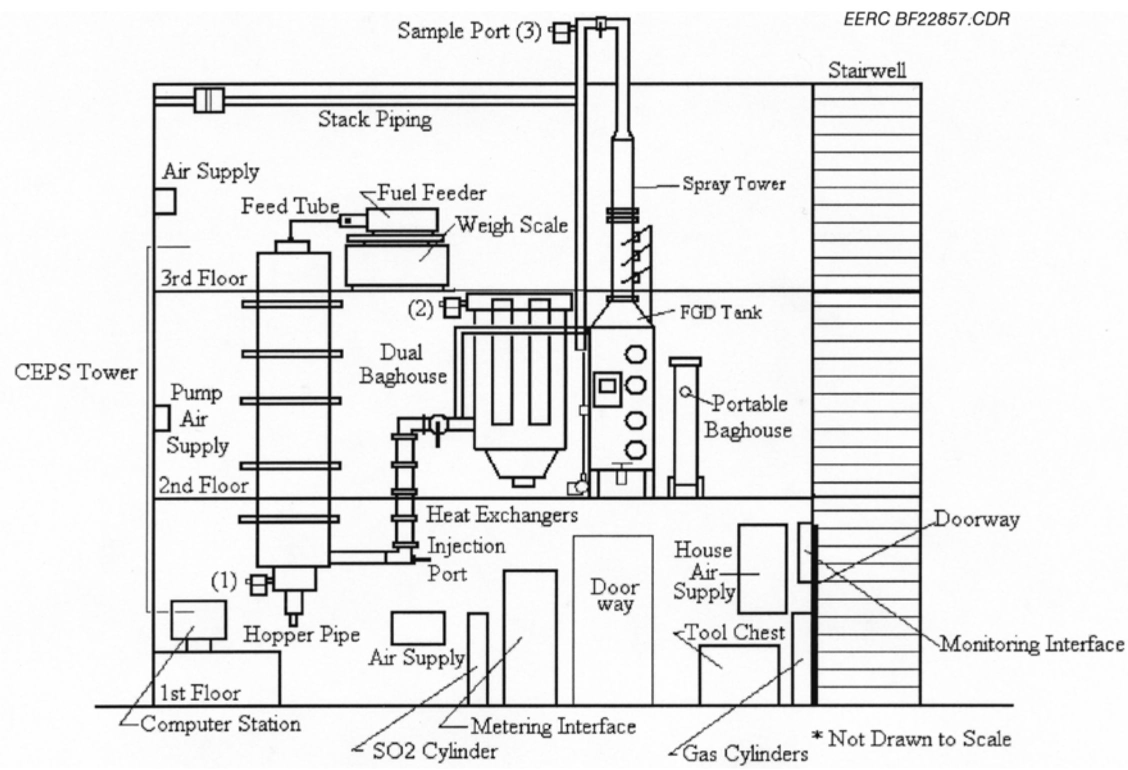


Figure 1. Schematic of the CEPS and flue gas desulfurization (FGD) system.

insulating refractory and high-temperature, fibrous insulating board. The overall system is housed inside a series of rectangular stainless steel sections bolted together. In juxtaposition to the CEPS, there is a small-scale tank and spray tower used to simulate sulfur-reduction scrubber systems in coal-fired power plants that can either be isolated from the CEPS when not in use or be a portion of the flue gas path for the combustion gases from the CEPS. This apparatus will be used to simulate an absorber spray tower system to evaluate three desiccants selected in Task 1. A rudimentary schematic of the CEPS and FGD layout is illustrated in Figure 1. The combustion gases will flow through the CEPS baghouse and then into the spray tower where it will be contacted by the desiccant stream in a countercurrent flow. If attainable within the time and dollar framework of the program, two fuels will be used to produce combustion gas for the spray tower absorber CEPS test. The two fuels would be a solid fuel and a nonsolid fuel. This determination will be made in the next quarter, and a formal test plan for the CEPS testing will be formulated.

## RESULTS AND DISCUSSION

In this quarter, Task 1 was completed. This task consisted of evaluating multiple desiccants for use in this application. The specific criteria used to evaluate the desiccants were:

- Adverse impact of the flue gas constituents on the desiccant.
- Maintenance frequency/complexity cost.
- Parts replacement.
- Desiccant makeup.
- Material handling.
- Impact of desiccant on system operation and cost.
- Flow characteristics when in solution.
- Amount of available property data.
- Permeability.
- Solubility limits.
- Removal of combustion products other than water.
- Desiccant capital cost.
- Heat transfer properties.
- Corrosiveness.
- Ability of desiccant to remove water from the exhaust stream.
- Environmental effects of desiccant slip.

The result of the review of the available information on desiccants was the selection of three desiccants to be tested in the EERC CEPS. Two of the desiccants chosen for further evaluation have potential corrosion issues depending on the type of materials used in construction. Additives used in industry to reduce the corrosivity of these desiccants were investigated but it was determined they would be ineffective in this application. The three desiccants were purchased and will be ready for the Task 2 testing in the next quarter.

Modeling simulations and calculations were also performed in this quarter. The three desiccants selected for testing in the CEPS were used in a simulated potential system and process-flow scheme. Several conditions of operation were used to aid in determining the best possible operational parameters that could be used in the CEPS testing to obtain meaningful results. The test conditions will reflect this effort in the next quarter.

A statement of responsibilities for the outlined tasks and who will be the lead investigator for these tasks were formalized and agreed upon by SWPC and the EERC. Task responsibilities are provided in Table 1.

## CONCLUSIONS

Work on this project is proceeding as scheduled. A kickoff meeting was held, and the project communication protocols were established between team members. Additional members will be added to the Industrial Advisory Board in the next quarter. The project is divided into ten tasks, and Task 1 was completed in this quarter. Task 1 was the review and selection of desiccants for testing in Task 2. Three desiccants were chosen for further evaluation in Task 2. These desiccants have been ordered and will be available for the Task 2 tests. Task 2 was initialized, and modeling efforts were performed to aid in the development of the test procedure and process conditions for the combustion testing. Partial inspection and shakedown of some of the equipment to be used in the combustion testing were performed.

**Table 1. Statement of Responsibility for Tasks in Project Proposal**

| Task | | Lead / Support | | |
|---|---|---|---|---|
| | | Engineering | Procurement | Construction |
| 1 | Desiccant Selection | SWPC | SWPC | NA[1] |
| 2 | Desiccant Bench-Scale Test Evaluation | | | |
| | 2.1 Identify Desiccants to be tested | SWPC/EERC | NA | NA |
| | 2.2 Test Procedure | EERC/SWPC | NA | NA |
| | 2.3 Procure Materials and Set Up Test Rig | EERC | EERC | EERC |
| | 2.4 Conduct Test | EERC | NA | NA |
| | 2.5 Issue Report | EERC | NA | NA |
| 3 | Test Plan Development | | | |
| | 3.1 Determine Test Objectives ($H_2O$ extraction, desiccant interaction with flue gas) | SWPC/EERC | NA | NA |
| | 3.2 Determine Key Variables (flue gas compositions, temperatures, desiccant flow rates, desiccant concentrations, etc) | SWPC/EERC | NA | NA |
| | 3.3 Determine Scale of Test | EERC/SWPC | NA | NA |
| | 3.4 Determine Duration/Schedule of testing | EERC/SWPC | NA | NA |
| | 3.5 Determine Instruments Required | EERC/SWPC | NA | NA |
| | 3.6 Integration of Test Equipment into EERC Facility | EERC | NA | NA |
| | 3.7 Develop Test Procedure | EERC/SWPC | NA | NA |
| 4 | Test Facility and Equipment Design | | | |
| | 4.1 Conceptual Material and Energy Balances | SWPC | NA | NA |
| | 4.2 Test Process P&ID[2] | SWPC/EERC | NA | NA |
| | 4.3 Test Equipment Functional Specification | SWPC/EERC | NA | NA |
| | 4.4 Test Equipment Detailed Design | EERC | NA | NA |
| | 4.5 Absorber/Regenerator Design Review | EERC/SWPC | NA | NA |
| | 4.6 Modification Plan to Existing EERC Facility | EERC | NA | NA |
| 5 | Test Equipment and Materials Construction and Procurement | EERC | EERC | EERC |
| 6 | Test Equipment Installation and Commissioning | EERC | EERC | EERC |
| 7 | Testing | | | |
| | 7.1 Operation of Test Rig | EERC | NA | NA |
| | 7.2 Data Collection | EERC | NA | NA |
| | 7.3 Witness | SWPC | NA | NA |
| 8 | Test Data Evaluation | | | |
| | 8.1 Test Report | EERC | NA | NA |
| | 8.2 Individual Component Evaluation | EERC | NA | NA |
| | 8.3 Desiccant Efficacy Evaluation | EERC | NA | NA |
| | 8.4 Desiccant Carryover Evaluation | EERC | NA | NA |
| | 8.5 Component Interaction Evaluation | EERC | NA | NA |
| | 8.6 System Evaluation | EERC | NA | NA |
| | 8.7 Test Report Review | SWPC | NA | NA |
| 9 | Commercialization Plan | | | |
| | 9.1 Materials of Construction Impact Evaluation | EERC | NA | NA |
| | 9.2 Generate Pulverized Coal (PC) and IGCC[3] Simulation Models | SWPC | NA | NA |
| | 9.3 Conceptual Mass / Energy Balances for PC and IGCC | SWPC | NA | NA |
| | 9.4 Assessment of PC and IGCC Water Removal System | SWPC/EERC | NA | NA |
| | 9.5 Full-Scale Cost Estimates | SWPC/EERC | NA | NA |
| 10 | Program Management | | | |
| | 10.1 Program Management | EERC/SWPC | EERC | EERC |
| | 10.2 Contract Administration | EERC/SWPC | EERC | EERC |

[1] Not applicable.
[2] Piping and instrumentation diagrams.
[3] Integrated gasification combined cycle.